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贵州珍稀濒危植物皱叶瘤果茶的种群生态特征研究*

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摘要：皱叶瘤果茶（*Camellia rhytidophylla*）是颇具经济价值的特有濒危植物，分布于贵州高原亚地区（Ⅲ D10d）开阳县花梨镇洛旺河流域海拔 573~920 m 的常绿阔叶落叶混交林中，研究其种群生命特征与保育利用具有重要意义。选择皱叶瘤果茶疑似分布区（6 km²）开展踏查，在密集分布区设置样地进行详查，分析其种群结构、动态和空间分布格局。结果表明：皱叶瘤果茶种群结构为增长型，幼龄树在种群中占的比重达46.38%，种群密度大小为幼龄树>中龄树>成年树，种群存活曲线为 Deevey-Ⅲ型，死亡率曲线和消失率曲线分别在Ⅰ龄期和Ⅳ龄期出现 2 个高峰，随后又同时在Ⅲ龄期和Ⅵ龄期出现 2 个低谷。2 个样地内的幼树种群在所有尺度下均呈集群分布，中龄树种群在小尺度上呈集群分布，在大尺度上则表现为随机分布，成年树种群由于人为活动干扰和生境异质性而使空间分布格局明显不同。各发育阶段的空间分布格局有较大差异，关系不密切，均表现为负相关或不相关。皱叶瘤果茶种群空间分布格局是其物种生物学特性、生境异质性及人为干扰等因素共同作用的结果，自然繁殖率极低是限制种群扩散的关键因素，生境异质性、山丘阻碍种子散布以及人类活动的干扰是其种群狭限分布的主要原因。

关键词：皱叶瘤果茶；特有植物；种群生态特征；空间分布格局；静态生命表
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Population Ecological Characteristics of the Rare and Endangered Plant *Camellia rhytidophylla* from Guizhou

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Abstract: *Camellia rhytidophylla* is endemic and endangered and with important economic species, from the Ⅲ D10d in eastern Asia, which distributed at 573-920 m in evergreen broad-leaved deciduous mixed forest in Luowang river valley of Kaiyang county. So, it is significant to study the population characteristics, conservation and utilization. We took general survey in suspected distribution area about 6 square kilometers, set up plots in dense area, and analyzed the population structure, development and spatial distribution pattern. The results showed that the structure of *C. rhytidophylla* populations were increasing and the proportion of young tree in population was 46.38%. The size of population density was young shrubs>middle-aged shrubs>adult shrubs. The survival curve of population was Deevey-Ⅲ model. There were 2 peaks in the Ⅰ and Ⅳ age-classes on the mortality rate curve and disappearance rate curve respectively, then there are 2 troughs in the Ⅲ and Ⅵ age -classed at the same time. The spatial distribution pattern of *C. rhytidophylla* significantly differentiated at different stages of development, the young individuals were aggregated at all spatial scales while the middle-aged individuals were aggregated at small spatial scales and randomly distributed at larger scales. Differences in the distribution of adult individuals could be attributed to arti-

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ficial disturbance and habitat heterogeneity. The spatial pattern was not close in different stages of development, which all showed negative or no correlation. The spatial distribution pattern of *C. rhytidophylla* was the interaction of the factors, such as its biological characteristics, habitat heterogeneity, and artificial disturbance, etc.. The key factor limiting population development was low natural reproduction rate; the primary factors causing its endemic distribution mainly included habitat heterogeneity, topographical constraints on seed dispersal and artificial disturbance.

Key words: *Camellia rhytidophylla*; Endemic plant; Population ecological characteristics; Spatial distribution pattern; Static life table

Population ecology examines characteristics of individuals, populations, communities, and connects various fields of ecology (Zhang *et al.*, 2007a). Population dynamics are the core of this branch of ecology, and changes in the number and spatial distribution of populations are the focus points of population ecological research. Life tables and survival curves are important tools for statistical analysis of dynamic changes in populations (Xu *et al.*, 2005; Yan *et al.*, 2001). Analysis of spatial patterns is an important method for studying interactions between populations and relationships between populations and the environment. Different spatial patterns reflect the status of resource used by populations and can reveal the rules behind population growth and succession (Condit *et al.*, 2000; Zhang, 1998).

The species of the genus *Camellia* (family Theaceae), which have high economic and ornamental value, are an important component of subtropical evergreen broad-leaved forests. Many species of the tea group (such as *C. sinensis* and *C. assamica*) are planted long for tea production in China and provided renowned beverages in the international market, and now widely cultivated in many parts of the world. More than 60 species of the sect. *Oleifera* Chang and sect. *Camellia* (L.) Dyer, which have seeds with high oil content, are excellent materials for food and industrial uses. In addition, some species of genus *Camellia* and several other genera of Theaceae are important horticultural species with high ornamental value, such as elegant shape, abundant flowers, and long flowering period (they bloom in winter after other plants have senesced) (DCP, 2014; Zhang and Ren, 1998; Li *et al.*, 2005b). These plants are popular in flower markets and possess strong international reputations with their long history of cultivation.

Guizhou Province is located in the northern edge of the subtropical zone and has abundant *Camellia* germplasm, including *C. rhytidophylla* Y. K. Li et M. Z. Yang. *C. rhytidophylla* is endemic to the Guizhou Plateau Subregion (IIID10d) (Central China phytogeographic area, Eastern Asiatic Region) (Wu *et al.*, 2010) and is known as the "iron filings tree" (DCP, 2014). The species occurs in the understory of mixed evergreen and deciduous broadleaved forests in warm, humid habitats at elevations between 570 and 920 m.

C. rhytidophylla is an evergreen shrub that typically grows to 2.0–5.0 m, and was identified and named in 1987 (Li and Yang, 1987). This species is rare and is only distributed in Kaiyang County, Guizhou Province. Its dark green leaves, white flowers, and aesthetic shape have made it to be an ideal species for afforesting and beautifying, with cluster plantings in courtyards and gardens. With its resistance to sulfide, planting this species in mining areas that have severe air pollution might help to reduce sulfide contamination (Zou, 2001). Systematic exploration of *C. rhytidophylla* will promote the development and protection of germplasm resources. Various researchers have studied the introduction and cultivation of *C. rhytidophylla* and have reported on its leaf anatomy and chemical content (Liu *et al.*, 2011b; Long, 2013; Zhang *et al.*, 2010; Zou, 2001; Zou and Lou, 1995). However, systematic ecological research is lacking for this species, and no population ecology studies have been published to date. In this study, we conducted systematic field investi-

gations of the population structure and dynamics and spatial distribution of *C. rhytidophylla*. We discuss the ecological characteristics, endangered status, environmental adaptability of *C. rhytidophylla* populations, and the factors that limit survival and development of its populations, and we attempt to provide a scientific basis for its effective protection and the rational use of its germplasm. Through this work, we also hope to provide a reference for further studies of floristic composition and population characteristics of other plants in the Guizhou Plateau as well as research on endemic and rare plants in other regions of the world.

1 Materials and methods

1.1 Study sites

We examined the reported natural distribution areas of *C. rhytidophylla* (Li and Yang, 1987) and selected a study area in the evergreen broad-leaved deciduous mixed forest region in the Luowang River valley of Huali Town, Kaiyang County, Guizhou Province, China. *C. rhytidophylla* was distributed at elevations between 570 and 920 m from 27°06′51″ to 27°08′03″ N and 107°04′08″ to 107°05′31″ E. We surveyed the 4.14 km^2 region in which *C. rhytidophylla* was thought to be distributed and conducted a detailed investigation within a 1.05 km^2 area where it formed dense populations. These areas occurred in a mountain-and-hill zone (erosion landform) with scattered flat areas interlaced with streams and valleys. The climate was subtropical humid monsoon with average annual rainfall of 1 230 mm, average annual humidity of approximately 70%, maximum and minimum temperatures of 35.4 ℃ and −10.1 ℃ (annual average = 13.6 ℃), and cumulative annual temperature of 5 000−5 100 ℃. The majority (75%) of rainfall occurs in May-October (Agricultural regional planning committee of Kaiyang county, 1989; Liang and Zhang, 2014).

C. rhytidophylla grows individually or in clusters. The plant communities in which *C. rhytidophylla* occurs are species-rich and structurally complex and include 21 families and more than 30 species. The tree layer (5−12 m, 60%−80% canopy cover) includes *Cyclobalanopsis myrsinifolia*, *Cinnamomum camphora*, *Idesia polycarpa* var. *vestita*, *Terminalia amtay*, *Podocarpus nagi*, and *Ilex franchetiana* Loes; *C. myrsinifolia* is the dominant canopy species. The shrub layer (2−5 m, 40% canopy cover) includes *Ziziphus jujuba* var. *spinosa*, *Nandina domestica*, *Panax pseudoginseng* var. *notoginseng*, *Rhapis excelsa*, and *Elaeagnus umbellata*. The herbaceous layer (0.2 −1.2 m, approximately 25% canopy cover) mainly includes *Pteridium aquilinum* var. *latiusculum*, *Nephrolepis auriculata*, *Pyrrosia lingua*, *Selaginella uncinata*, *Polygonum perfoliatum*, *Delphinium delavayi* var. *pogonanthum*, *Aspidistra elatior*, and *Miscanthus sinensis*. Some interlaminar lianas, such as *Smilax china* and *Sargentodoxa cuneata*, are also present.

1.2 Field study

Field surveys and data collection were conducted during 2013−2014 within the selected sites in Daxianggou Section, Qingjiang Village (Guizhou Plateau Subregion IIID10d). Based on the survey results, two representative sampling areas (A and B) were chosen on the North Slope in Daxianggou, where *C. rhytidophylla* was densely distributed (Table 1). We established one 50 m × 50 m plot (one of the plot boundaries was oriented perpendicular to the slope and another was parallel to the slope) in each sampling area. We measured the vertical distance of each *C. rhytidophylla* plant to the edge of the sampling

Table 1 Geographical location and habitat characteristics of *Camellia rhytidophylla* sampling sites

Sampling site	Geographical coordinates	Elevation /m	Sample area /m^2	Canopy coverage	Aspect	Slope	Soil type	Soil pH
A	27°07′18″N, 107°05′06″E	673	2500	0.8	51° NE	76°	Silty clay	Slightly acidic
B	27°07′22″N, 107°05′00″E	666	2500	0.6	23° NE	68°	Silty clay	Slightly acidic

plot using a rangefinder and recorded the coordinates, height, basal diameter, and crown size (north-south) of each plant. In each of the 2 500 m^2 plots, we established five 5 m × 5 m subplots to investigate species composition and height and canopy coverage of the shrub layer. We also established one 1-m^2 sample plot at the center of each subplot to measure species composition, height, and canopy coverage of the herbaceous layer.

1.3 Population age-class determination

C. rhytidophylla are short tree with many lateral branches, which made it difficult to obtain wood cores. Furthermore, destructive sampling to determine the age of individual shrubs would violate the principle of biodiversity protection. Therefore, we analyzed population age structure according to diameter class rather than age class as the reported research (Wang *et al.*, 2010; Zhang *et al.*, 2013), basal diameter (D) was used as a standard to categorize the diameter classes. The first diameter class was defined as $D = 0-2$ cm, with additional diameter classes defined in 2-cm increments. We plotted diagrams of population diameter-class structure from these data.

1.4 Life table preparation and curve plotting

We used the method of Feng *et al.* (2003) to generate a time-specific life table for *C. rhytidophylla* using the diameter-class data. The order of diameter classes from small to large was considered as a reflection of age classes from young to old; the first diameter class corresponded to the first (youngest) age class and so on. The numbers of plants in each diameter class were counted and the data were standardized. Age (diameter) classes were plotted on the horizontal axis, and the standard survival number (l_x) was plotted on the vertical axis to obtain the survival curve. Additionally, we used q_x and K_x as the vertical axis to plot the mortality and disappearance rate curves, respectively.

1.5 Spatial distribution pattern analysis

Population spatial distribution patterns were analyzed using spatial point pattern analysis (SPPA) (also called Ripley's *K*-function) (Cetis and Franklin, 1987; Zhang and Meng, 2004; Li *et al.*, 2005a). The basic formula for Ripley's K is:

$$\hat{K}(t) = \frac{A}{n^2}\sum_{j=1}^{a}\sum_{i=1}^{n}\frac{1}{W_{ij}} I_t(u_{ij}) \quad (i \neq j) \qquad (1)$$

Where A is plot area, n is the total number of points, t is distance scale, and u_{ij} is the separation between shrub i and shrub j. When u_{ij} is $< t$, $I_t(u_{ij}) = 1$; when u_{ij} is$>t$, $I_t(u_{ij}) = 0$. W_{ij} is the ratio of the length of the arc of a circle that centers at point i and with radius u_{ij} and falls in area A to the circumference of the circle. W_{ij} reflects the probability that a point (plant) would be observed (Diglle, 1983; Haase, 1995).

For a simplified explanation of the results, we used the revised formula of Ripley's-K:

$$L(t) = \sqrt{\hat{K}(t)/\pi} - t \qquad (2)$$

for analysis of spatial distribution patterns. To evaluate the significance of the deviation of $L(t)$ from a random distribution, we used a Monte Carlo method and calculated the 99% confidence interval (CI) of $L(t)$ using 10 000 random spatial simulations (Zhang, 1998). When $L(t)$ was greater than the upper limit of CI, the distribution was aggregated; when $L(t)$ was within the CI, the distribution was random; when $L(t)$ was smaller than the lower limit of CI, the distribution was uniform.

Point (or multi-point) pattern analysis of two or more developmental stages examines the relationships between developmental stages (Condit *et al.*, 2000; Zhang and Meng, 2004). Its definition and calculation principle is:

$$\hat{K}_{12}(t) = \frac{A}{n_1 n_2}\sum_{j=1}^{n_1}\sum_{i=1}^{n_2}\frac{1}{W_{ij}} I_t(u_{ij}) \quad (i \neq j) \qquad (3)$$

Where n_1 and n_2 indicate the number of individuals (points) in Stage 1 and Stage 2, respectively; A, $I_t(u_{ij})$, and W_{ij} are as in Eq.(1); and i and j represent individuals in Stages 1 and 2, respectively.

Similarly, we used the Monte-Carlo method to examine the fitted $L_{12}(t)$ CI, to determine if a sig-

nificant correlation existed between Stages.

$$L_{12}(t) = \sqrt{\hat{K}_{12}(t)/\pi} - t \quad (4)$$

When $L_{12}(t)$ is greater than the upper limit of CI, the correlation is significantly positive; when $L_{12}(t)$ is within the CI, there is no correlation; when $L_{12}(t)$ is smaller than the lower limit of CI, the correlation is significantly negative. All analyses were performed using the ecological software package ADE-4 (Li *et al*., 2013).

2 Results

2.1 Distribution range, population density, and number of *C. rhytidophylla*

Through the field surveys, we identified that the natural distribution region of *C. rhytidophylla* covered a 4.14 km^2 area (2.3 km × 1.8 km), which consisted of a dense distribution in a 1.05 km^2 (1.5 km × 0.7 km) section and a sporadic distribution in the remaining area (Fig. 1). There were approximately 86 900 *C. rhytidophylla* individuals in the dense distribution region (The unweighted geometric mean total density in this area was 828 shrubs/ha, with the highest survey-area mean density being 1 368 shrubs/ha and the lowest being 444 shrubs/ha.), and 6 000 plants in the remaining area (average population density = 20 shrubs/ha). The natural distribution regions were narrow, the population was small, and the population distribution was extremely uneven (density varied from 1 368 to <20 plants/ha).

2.2 Diameter-class distribution and age structure of *C. rhytidophylla*

The diameter (D)-class distribution of *C. rhytidophylla* had a pyramidal form; young shrubs were most abundant, and there were fewer adult shrubs (Fig. 2). We examined a total of 414 individuals in the two 50 m × 50 m plots. Of these, 192 (46.38%) were young plants (D = 0−2.0 cm), 138 (33.33%) were middle-aged (D = 2.0−6.0 cm), and 84 (20.29%) were adult shrubs D > 6.0 cm. For shrubs with ground diameter ≤6.0 cm, the number of individual plants in the population rapidly decreased as the diameter increased, but this trend slowed for shrubs with ground diameter >6.0 cm, which indicated that the age structure of *C. rhytidophylla* took a "pyramid" shape and that its population was expanding.

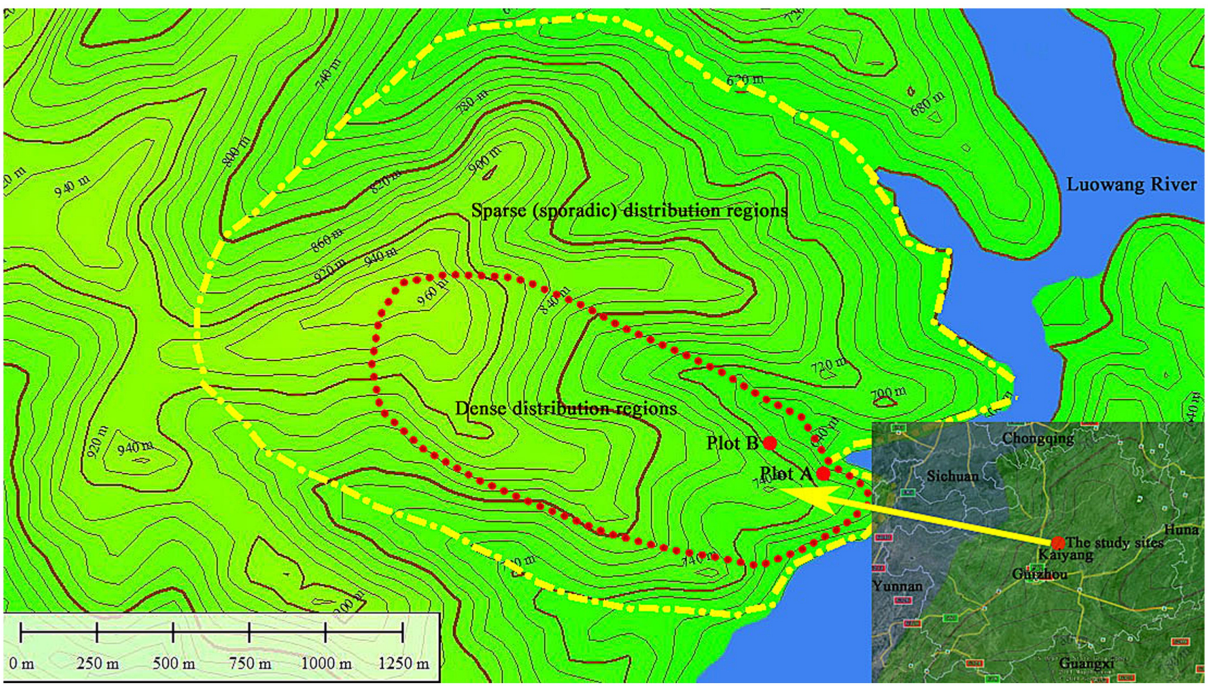

Fig. 1 Location and size distribution of endemic *Camellia rhytidophylla* population. Yellow dotted line indicates the overall distribution region; red dashed line indicates the dense distribution region; A and B are the locations of study plots

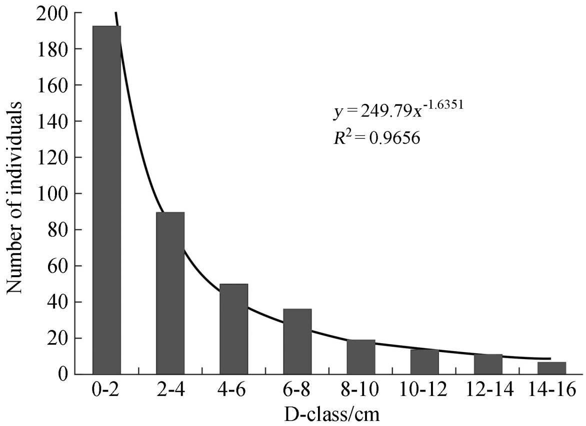

Fig. 2 Histogram of diameter (D) classes of *Camellia rhytidophylla* population

2.3 Time-specific life table of *C. rhytidophylla*

We established a time-specific life table for the *C. rhytidophylla* population (Table 2), which showed that life expectancy increased for shrubs in the first three age classes, decreased slightly in the fourth age class, and increased in the fifth age class again, and then sharply declined. The life-expectancy trend showed a "low-high-low" pattern that reflected differences in survival rate over different age classes. Besides, although there were large numbers of young shrubs, the survival rates of the first two age classes were significantly lower because of high mortality and disappearance rates that occurred during the first and second age classes. These results indicated that there were very few individuals that could survive to the next age class.

2.4 Survival, mortality, and disappearance rate of *C. rhytidophylla*

Survival, mortality, and disappearance rate curves for the *C. rhytidophylla* population were plotted (Fig. 3). The Deevey classification system recognizes three types of survival curves: Deevey-I, Deevey-II, and Deevey-III (Jiang, 1992); the survival curve of the *C. rhytidophylla* population was the Deevey-III type (Fig. 3A). Over the lifetime of *C. rhytidophylla*, the mortality and disappearance rate curves showed two peaks and two troughs (Fig. 3B). In addition to natural mortality, we observed that 22.5% of shrubs were logged, as evidenced by the remaining stumps.

2.5 Spatial distribution pattern of populations in different age classes

Point distribution patterns of *C. rhytidophylla* shrubs at three developmental stages (diameter classes) revealed differences in density among the stages (Fig. 4). Plot A included 520, 316, and 180 young, middle-aged, and adult shrubs/ha, respectively. Plot B included 248, 236, and 156 young, middle-aged, and adult shrubs/ha, respectively. Young shrubs were most abundant in both plots, followed by middle-aged shrubs, and adult shrubs were least abundant. Each of the developmental stages showed some degree of aggregated distribution. We used spatial point pattern analysis, with Ripley's K-function, to further explore the relationship between distribution and scale

Table 2 Time-specific life table for the *Camellia rhytidophylla* population

Age class	D/cm	x	Δ_x	a_x	l_x	d_x	q_x	L_x	T_x	e_x	S_x	K_x
I	0–2	1	2	192	1000.00	536.46	0.54	731.77	1656.25	1.66	0.46	0.77
II	2–4	3	2	89	463.54	208.33	0.45	359.38	924.48	1.99	0.55	0.60
III	4–6	5	2	49	255.21	67.71	0.27	221.35	565.10	2.21	0.73	0.31
IV	6–8	7	2	36	187.50	88.54	0.47	143.23	343.75	1.83	0.53	0.64
V	8–10	9	2	19	98.96	31.25	0.32	83.33	200.52	2.03	0.68	0.38
VI	10–12	11	2	13	67.71	15.63	0.23	59.90	117.19	1.73	0.77	0.26
VII	12–14	13	2	10	52.08	20.83	0.40	41.67	57.29	1.10	0.60	0.51
VIII	14–16	15	2	6	31.25	31.25	1.00	15.63	15.63	0.50	0.00	1.00

D, diameter class (basal diameter); x: midpoint age (midpoint diameter, cm); Δ_x, width of age (here as width of diameter, cm. According to the biological characteristics of the *C. rhytidophylla* population, 2 cm = one age); a_x, number of surviving individuals; l_x, proportion of individuals surviving to age x ($l_x = a_x/a_0 \times 1000$); d_x, number of dead individuals from age x to $x+1$ ($d_x = a_x - a_{x+1}$); q_x, mortality rate from age x to $x+1$ ($q_x = d_x/l_x$); L_x, mean number of individuals surviving from age x to $x+1$ ($L_x = (l_x + l_{x+1})/2$; T_x, total number of individuals surviving from age x ($T_x = \sum L_x$); e_x, life expectancy at age x ($e_x = T_x/l_x$); S_x, age-specific survival ($Sx = l_{x+1}/l_x$); K_x, age-specific mortality ($K_x = \ln[l_x] - \ln[l_{x+1}]$).

(Fig. 5). There were remarkable differences in the distribution patterns of *C. rhytidophylla* according to scale at different stages of development in plot A. Young shrubs were significantly aggregated at all scales (Fig. 5A-1); Middle-aged shrubs (Fig. 5A-2) were significantly aggregated from 0 to 7 m and had a random distribution at larger scales (7–25 m); Adult shrubs (Fig. 5A-3) were significantly aggregated in the ranges of 0–3 m and 5–7 m and showed a random distribution in the ranges of 3–5 m and 7–25 m.

Significant differences in distribution patterns of *C. rhytidophylla* according to scale were also observed in plot B for different developmental stages. Young shrubs (Fig. 5B-1) were significantly aggregated at all scales; Middle-aged shrubs (Fig. 5B-2) were significantly aggregated within the scale ranges of 0–8 m and 19–25 m and were randomly distributed in the 8–19 m range; adult shrubs (Fig. 5B-3) showed a random distribution in the 1–4 m range and an aggregation distribution at scales >4 m.

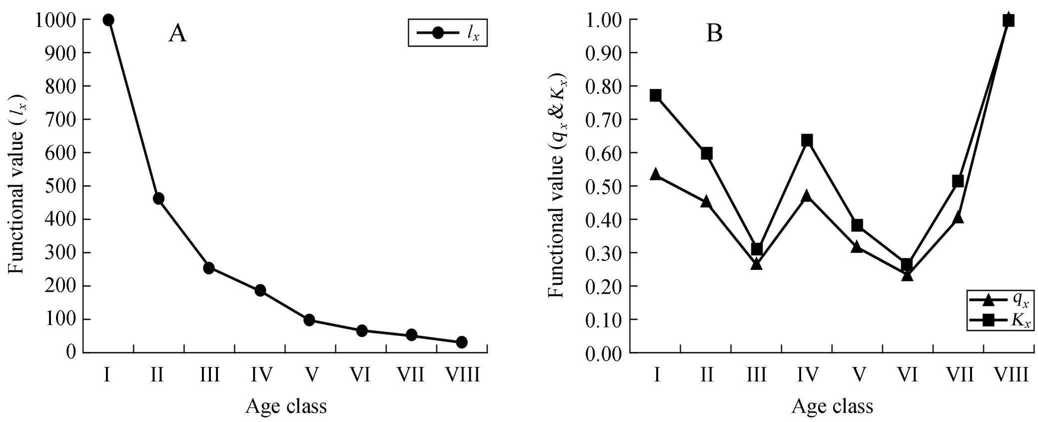

Fig. 3 Survival curve l_x (A); mortality rate curve q_x and disappearance rate curve K_x (B) of the *Camellia rhytidophylla* population

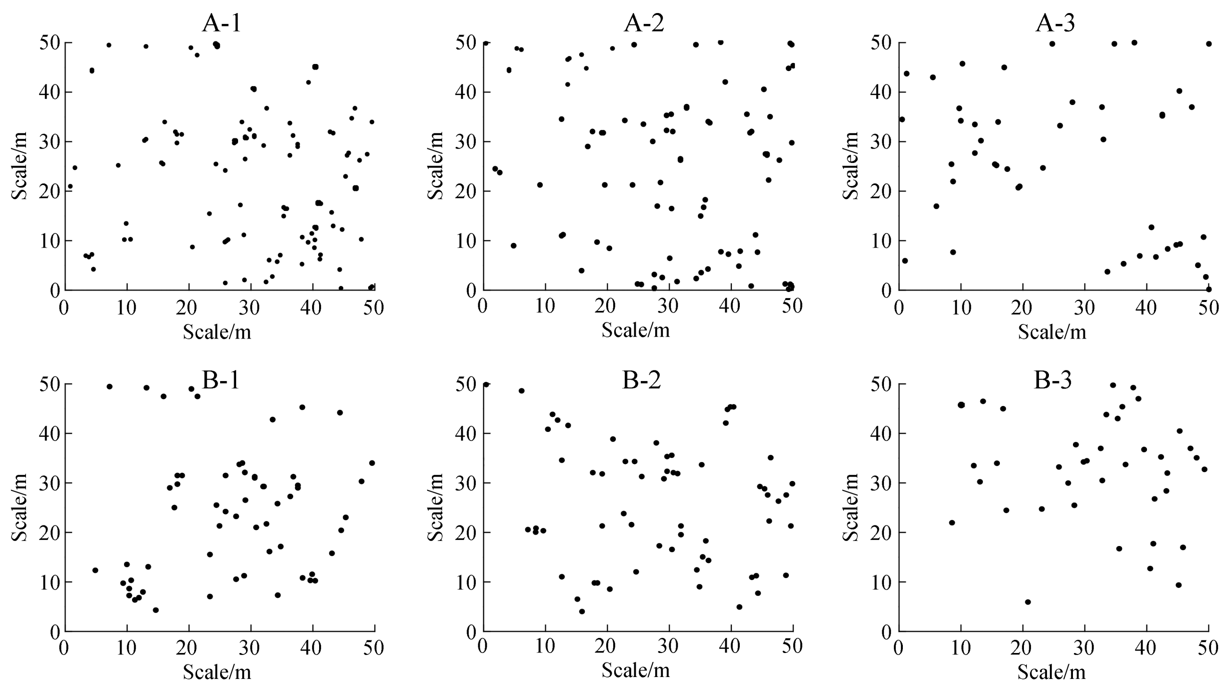

Fig. 4 Point pattern of individual *Camellia rhytidophylla* plants of different growth stages

Panels A-1, A-2, and A-3 represent young, middle-aged, and adult shrubs in plot A, respectively; panels B-1, B-2, and B-3 represent young, middle-aged, and adult shrubs in plot B, respectively. Axes represent plot dimensions (50 m × 50 m)

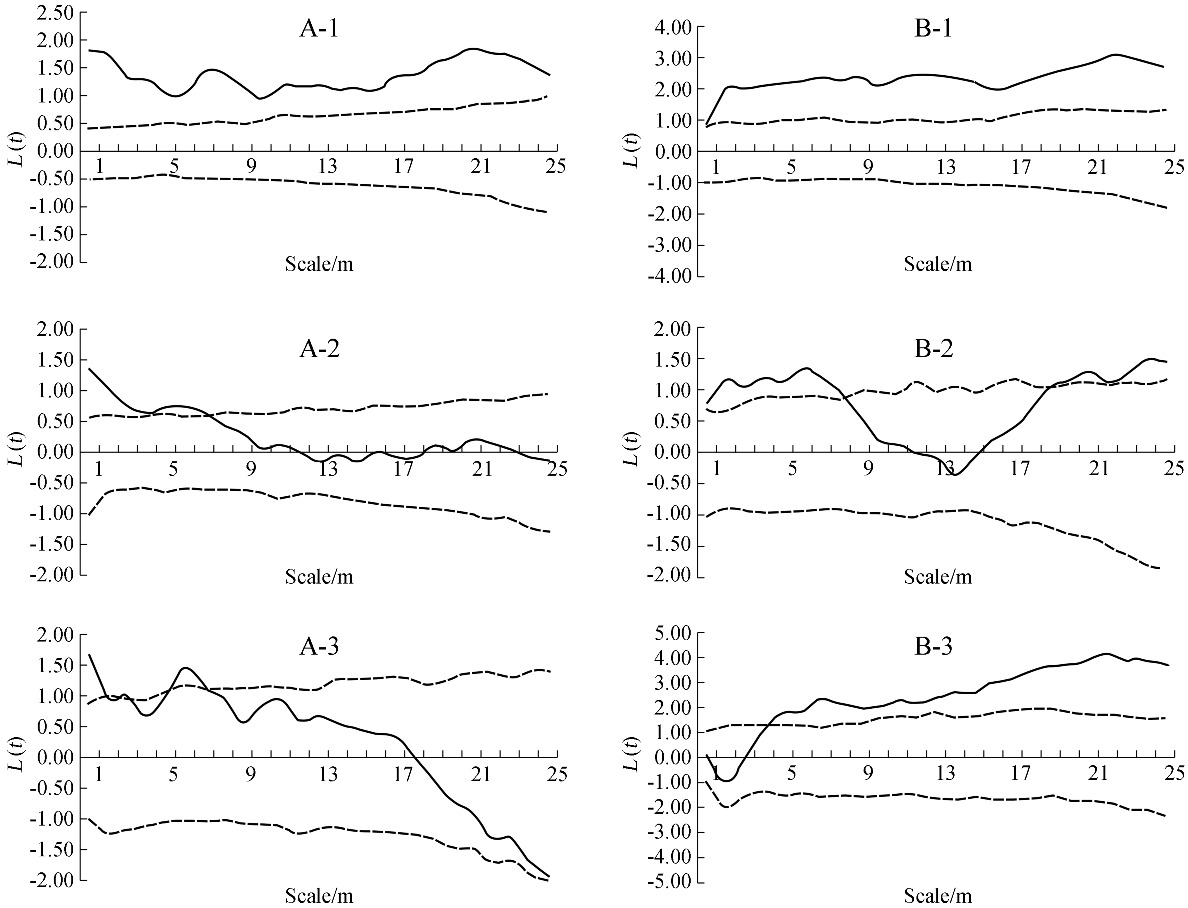

Fig. 5 Point pattern analysis of different growth stages of *Camellia rhytidophylla*. Solid lines denote the $L(t)$ (Functional value at scale t) curves calculated from data and dotted lines denote the fitted envelop curves (99% confidence interval). Panels A-1, A-2, and A-3 represent young, middle-aged, and adult shrubs in plot A, respectively; panels B-1, B-2, and B-3 represent young, middle-aged, and adult shrubs in plot B, respectively. We used the interval of t at 1 m for the analysis, and the maximum value of t was equal to half of the length of a sample plot (25 m). Distance (m) is shown on the x-axis

2.6 Spatial correlation analysis at different development stages

We analyzed spatial correlations between the three developmental stages of *C. rhytidophylla* using Ripley's K-function (Fig. 6). In plot A, at the 0−9 m scale, measured $L_{12}(t)$ values overlapped with the lower envelop curve, and at the 9−25 m scale, measured $L_{12}(t)$ values were between the upper and lower envelop curves (Fig. 6A-1). This showed a negative or near-negative correlation between young and middle-aged shrubs from 0 to 9 m, and no correlation at larger scales. Young and adult shrubs were negatively or near-negatively correlated at the 4−13 m scale and had a significant negative correlation at smaller and larger scales (Fig. 6A-2). There was no obvious correlation between middle-aged and adult shrubs at any scale (Fig. 6A-3). In plot B, young and middle-aged shrubs had a negative or near-negative correlation at scales >7 m and had no correlation at other scales. Young and adult shrubs had a negative correlation or near-negative correlation at all scales, while middle-aged and adult shrubs showed no correlation at any scale (Fig. 6B).

3 Discussion

The results of survival analysis showed that the survival curve of the *C. rhytidophylla* population was a typical Deevey-III type and its population was expanding. Nevertheless, approximately half of the young plants observed in our survey were seedlings,

and the others sprouted from stumps after middle-aged and adult shrubs were cut down or died naturally. This indicates that its sexual reproduction was not strong and that the expanding population is vulnerable. The peak death rates occurred in the first and fourth age classes, which might be attributed to intraspecific competition and artificial disturbance (e. g., logging.). *C. rhytidophylla* seedlings mostly grow in clusters of four to six plants. Intraspecific competition becomes more severe as a result of density-dependent constraints on the growth of young shrubs (Li *et al.*, 2013); ultimately, only one or two of the seedlings in the cluster can survive, leading to relatively high mortality rates in young shrubs. In addition, local villagers continue to harvest trees and shrubs (especially those with basal diameter of 5−8 cm) for selling, which was a major reason for the relatively high mortality and disappearance rates in the fourth age class. Artificial disturbance and competition decrease in older age classes, resulting in decreased mortality and disappearance rates. Increased mortality and disappearance after the sixth age stage could be a result of limited nutrient supply and predatory logging. Therefore, if effective protection measures are not taken in a timely fashion, the expanding population may stabilize or begin to contract as young trees grow and intraspecific competition intensifies.

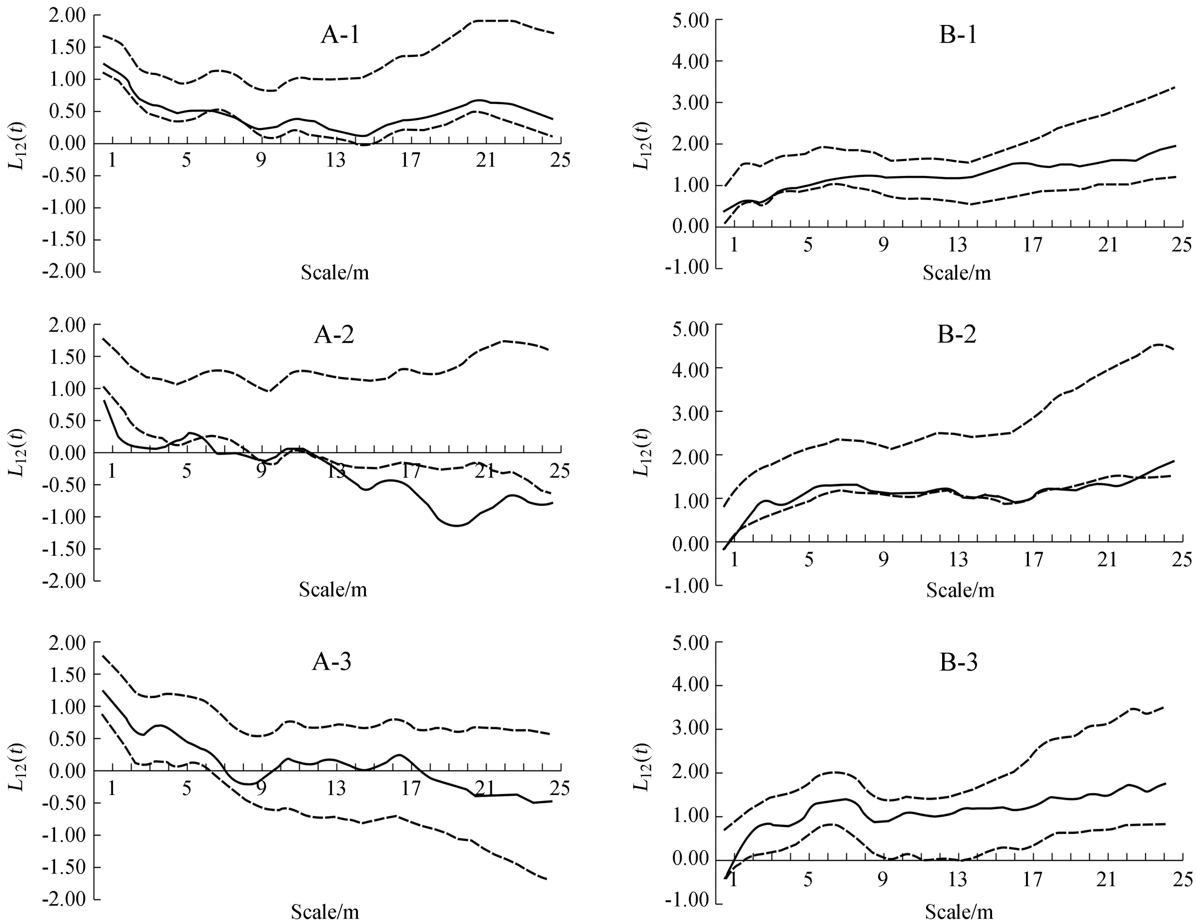

Fig. 6 Point pattern analysis of different growth stage associations of *Camellia rhytidophylla*. Solid lines denote the $L_{12}(t)$ curves calculated from data and dotted lines denote the fitted envelop curves (99% confidence interval). Panels A-1, A-2, and A-3 show the correlation between young and middle-aged shrubs, young and adult shrubs, and middle-aged and adult shrubs in plot A, respectively; panels B-1, B-2, and B-3 show the correlation between young and middle-aged shrubs, young and adult shrubs, and middle-aged and adult shrubs in plot B, respectively. We used the interval of t at 1 m for the analysis, and the maximum value of t was equal to half of the length of a sample plot (25 m). Distance (m) is shown on the x-axis

Spatial distribution patterns of plant populations are a result, in part, of biological factors and limits to seed dispersal, habitat heterogeneity, intraspecific and interspecific competition, and non-biological factors (He and Duncan, 2000; Li *et al.*, 2013; Lin *et al.*, 2011; Liu *et al.*, 2011a; Queenborough *et al.*, 2007; Yuan *et al.*, 2012; Zhang *et al.*, 2007b). The spatial distribution patterns of young and middle-aged *C. rhytidophylla* were similar in the two sampling plots, with young shrubs aggregated at all spatial scales, and middle-aged shrubs aggregated at small scales and randomly distributed at larger (>8 m) scales. These patterns could be related to biological characteristics such as seed dispersal mechanisms, individual multiplication, and intraspecific competition (Wang *et al.*, 2010). We observed that *C. rhytidophylla* fruit usually contained 4-6 seeds, leading to one or two seedlings in the cluster, which could explain the high level of aggregation (seedling clumps) in young shrubs. Additionally, many young shrubs sprouted from the stumps of middle-age and adult plants after logging and often grew in clusters of three to five plants. This is another important reason for the relatively high level of aggregation in young shrubs. Growth of young individuals and increased intraspecific competition lead to high mortality (density-induced self-thinning), resulting in less aggregation at middle-aged stages and leading to random distributions at some scales (Haase, 1995). Opposite distribution patterns were observed in plots A and B for adult *C. rhytidophylla* (the shrubs were aggregated at small scales and randomly distributed at larger scales in plot A, and the reverse in plot B). This might have been a result of habitat heterogeneity and artificial disturbance. Despite being located in the same plant community, plots A and B had different density and canopy coverage (Table 1). This would result in small-scale heterogeneity of factors including soil water content and light conditions. In addition, large-scale logging of middle-aged and adult shrubs by local villagers was another important reason for the differences in spatial distribution patterns between the two plots.

Intraspecific correlations provide a static description of relationships among individual plants in a population for a given time period. This includes spatial distribution and functional relationships within populations (Wang *et al.*, 2010). In this study, we observed negative or no spatial correlations in the *C. rhytidophylla* population at all developmental stages, which demonstrated that this species has different spatial patterns at different growth stages. This phenomenon can be attributed to natural thinning processes, disturbance patterns, and habitat heterogeneity. For example, soil water and nutrient conditions affect the spatial distribution of woody plants (John *et al.*, 2007; Zhang and Meng, 2004). Negative correlations, or the absence of correlations, between young *C. rhytidophylla* and middle-aged or adult shrubs could be explained by various factors. *C. rhytidophylla* populations have been affected by logging, and middle-aged shrubs were affected most severely. In addition, plant propagules could be transported large distances from mother shrubs on the steep hillsides where this species occurs.

The Guizhou Plateau Subregion (IIID10d) is a typical mountain and river valley in eastern Asia, characterized by widely distributed carbonate rocks with dissected topography (Wu *et al.*, 2010), high endemic plant resources, and distinct transitional tropical-to-subtropical characteristics. *Camellia* spp. are important components of subtropical evergreen and deciduous broad-leaved forests, and are especially common in the subcanopy and the shrub layer (Ying and Chen, 2011). Differences in plant survival among valleys and watersheds are a result of microclimate characteristics determined by topography; such characteristics are present in the *C. rhytidophylla* habitat (Fig. 1). Hills surrounding the river valley create a microclimate for *C. rhytidophylla* and lead to the evolution of its distinct biological characteristics. The hill environment and watershed limit the spread of *C. rhytidophylla* seeds, which results in a narrow, sparse, and uneven population dis-

tribution. In addition, low rates of seed set and high incidence of pests and diseases (Zou, 2001) limit the expansion of the *C. rhytidophylla* population.

In conclusion, a combination of geographic and biological characteristics has resulted in the narrow distribution of this endemic species, and its populations are currently endangered as a result of anthropogenic activity. Protection of rare and endangered plants is an important priority of biodiversity preservation. We found that the population structure of *C. rhytidophylla* was relatively stable; if protected, this species could survive and proliferate. The key is to effectively protect the native forest ecosystem in which *C. rhytidophylla* is found. In addition, artificial propagation and reintroduction can help to expand *C. rhytidophylla* populations, and horticultural use of this species can provide an effective means of conserving its germplasm.

The key scientific problem of conservation biology has always been the conservation and utilization of the biodiversity of rare and endangered plants with small populations. This paper showed that the distribution of *C. rhytidophylla* was very narrow. Habitat heterogeneity and artificial severe disturbance caused some limitations for the seed dispersal, population self propagation, diffusion and their stability. So we suggest that: 1) *C. rhytidophylla* should be included in the rare and endangered species protection list Redbook, so that more people know it and enhance people's protection awareness. We also should establish nature reserves for the species and protect the ecological environment, population and its biodiversity. 2) On the basis of in situ conservation, we suggest that more research about population characteristics and the propagation rules should be done to solve the propagation problem, to expand the population and its distribution area by cultivating seedling reintroduction, helping population growth and enhanced its reproduction and dispersal ability. At the same time, we could plant in different places and do production and application test, promote the transformation of the characteristic resources advantage into economic advantage, and strengthen the protection of germplasm resources in the production and application. All of these have important significance and practical value for the development of conservation biology and the construction of regional ecological environment.

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